Correction to “A statistical study of the propagation characteristics of whistler waves observed by Cluster”

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[1] In the paper "A statistical study of the propagation characteristics of whistler waves observed by Cluster" by Oleksiy Agapitov et al. (*Geophysical Research Letters*, *38*, L20103, doi:10.1029/2011GL049597, 2011), the incorrect reference frame (i.e., ISR2) was used to analyze the data. In Figure 2, a statistical analysis of the distribution of wave-normal angles as a function of latitude was presented. The results were obtained using data from the STAFF-SA instrument from the Cluster Active Archive (CAA), by assuming that the data was in the ISR2 coordinate system as written in the data description [*Cornilleau-Wehrlin et al.*, 1997; *Cornilleau-Wehrlin and STAFF Team*, 2011]. Unfortunately, recently it became evident that the true reference frame system of STAFF-SA data in the CAA is the SR2 (Spin Reference 2) coordinate system, which differs from the ISR2 (inverted SR2) by the inverted signs of the *Y* and *Z* axes. We have re-analyzed all of the data in the correct reference frame (i.e., SR2). The results of the new analysis are presented in Figure 1. In the present correction we describe the newly-obtained results and discuss how they impact the discussion in our original paper.

[2] Identification of the error only recently became possible when the data of the STAFF-SC instrument in the burst mode, namely, waveforms with a sampling rate of 450 samples per second (that were obtained on January 26, 2001) became available in the CAA. Making use of this data, we performed cross-calibration tests between the STAFF-SC waveforms and the STAFF-SA spectrum matrices. For the comparison, we used observations from a whistler wave that had a frequency of 100 Hz (0.15 of the local f_{ce}). For both STAFF-CA and STAFF-SA we determined that the wave had a circular polarization. The wave-normals determined from the STAFF-SA and STAFF-SC had different signs for the *Y* and *Z* components. The vector rotation with respect to the background magnetic field was right-handed from the STAFF-SC (as expected for whistler waves), but left-handed from the STAFF-SA. Since the coordinate system of the STAFF-SC has been verified using FGM data, the results unambiguously demonstrate that the true coordinate system of the STAFF-SA data in the CAA is SR2, not ISR2. The STAFF team, after verification, has confirmed that STAFF Spectral Matrix (SM) and Power Spectral Density (PSD) data at CAA are in SR2 reference frame and not in ISR2 as previously written by mistake (N. Cornilleau-Wehrlin, personal communication, 2012). The CAA documentation has now been modified accordingly by the STAFF team.

[3] The corrected probability distribution functions (PDF) of the whistler wave-normal direction θ (relative to the background $\vec{B}_0$ at the magnetic latitude, λ, are shown in Figure 1 for waves with amplitudes greater than 1 pT. The PDF of the hiss in the day and night sectors of the magnetosphere for *L*-shells $2 < L < 5$ are shown in Figures 1d and 1g, respectively. Figure 1l provides the equatorial θ distributions ($\lambda < 5$). The distribution is consistent with the numerical results for plasmaspheric hiss, as presented by *Bortnik et al.* [2011]. Some differences are observed in the night sector, where groups of waves with a $\theta \sim 10°$–$20°$ at λ from 10° to 30° are observed. The total number of wave events with a propagation direction to and from the equator for the hiss are approximately equal. The main difference of the latitudinal dependence of θ was obtained subsequent to the corrections for the lower band (LB) chorus, as shown in Figure 1e (the day sector), Figure 1h (the night sector), and Figure 1l (the equatorial distribution). An increase in θ with latitude is observed (the wave normals approached the resonance cone at λ of approximately 35°), which can be explained by numerical simulation [*Breuillard et al.*, 2012]. However, the amplitude of these oblique waves decreases with λ due to wave attenuation [*Bortnik et al.*, 2006]. The attenuation of the oblique LB chorus is more significant in the night sector (Figure 1h). A quasi-parallel to the background magnetic field waves ($\theta \sim 10°$–$30°$) is simultaneously observed and this group dominates at a λ from 10° to 30°. The results are consistent with the distribution obtained from POLAR measurements by *Haque et al.* [2010]. The LB chorus wave normals tend to become transverse only at $\lambda > 40°$, where the wave frequency becomes less than the local lower hybrid frequency and reflection can occur. The equatorial distribution of the LB chorus indicates that waves, with amplitudes greater than 1 pT, propagate mainly from the equator. The equatorial distribution of λ has a maximum at $\theta = 60°$ in the day sector and at a $\lambda = 13°$ in the night sector (close to the THEMIS observations presented by *Li et al.* [2011]). A secondary maximum is observed at $\theta = 60°$ in the day sector (at $\sim$70° from THEMIS data [*Li et al.*, 2011] and $\sim$60° from a ray tracing [*Breuillard et al.*, 2012]), and at $\theta = 45°$ during the night sectors formed by reflected waves that return to the equator. The Upper Band (UB) chorus statistics are pure due to the limitation of the STAFF-SA frequency band (the upper limit was 4 kH). Therefore, only a *L*-shell greater than 5 could be processed. The same tendency for increasing θ with latitude is observed (Figures 1f, 1i, and 1m). The UB chorus wave normals reach the resonance cone at $\lambda \sim 30°$, close to the results obtained from POLAR measurements [*Haque et al.*, 2010]. However, the variance of the equatorial θ PDF is much greater than

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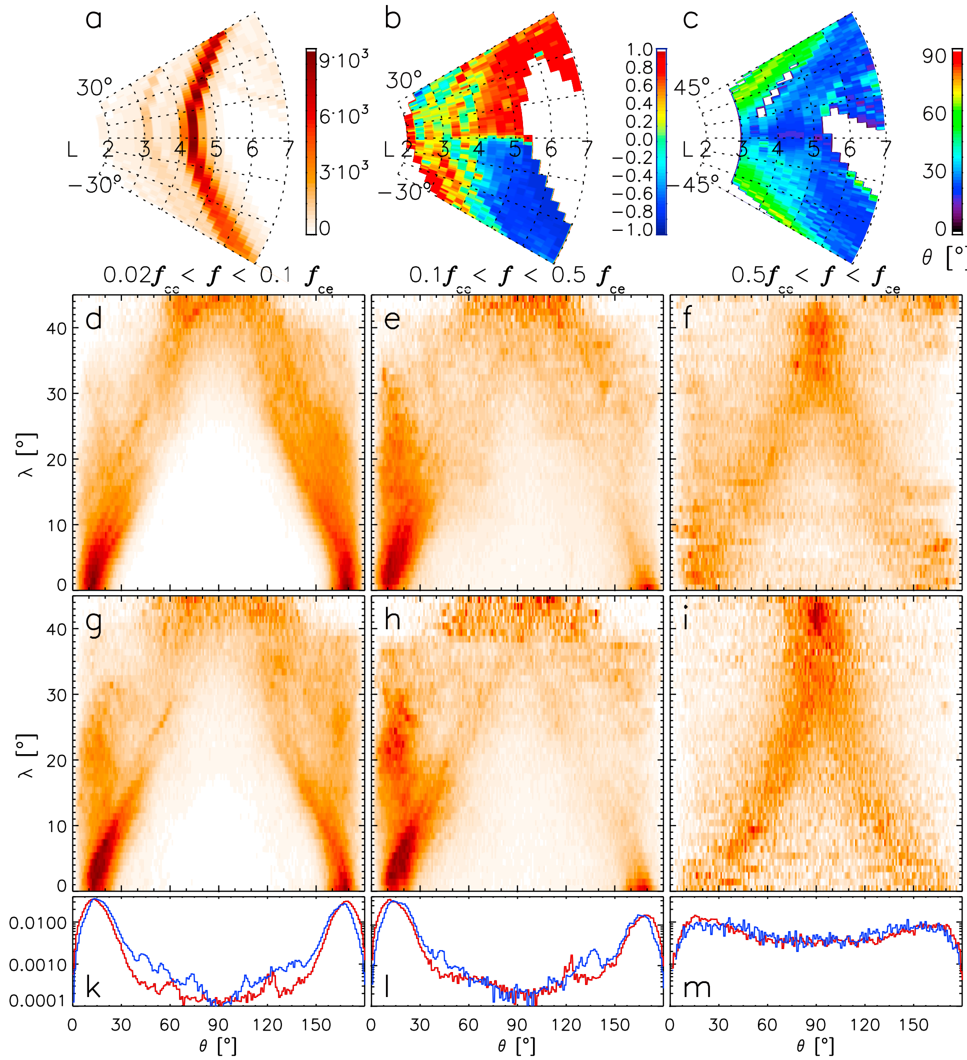

Figure 1. (a) The distribution of CLUSTER STAFF-SA measurements from 2001 to 2010. (b) The dominant direction of the Poynting flux for whistler waves in a chorus frequency range ($0.1\,f_{ce} < f < 1.0\,f_{ce}$). The direction is characterized by the normalized parameter $(N_a - N_o) / (N_a + N_o)$, where N_a and N_o are the number of spectra having a Poynting flux directed along ($\vec{k} \cdot \vec{B} > 0$) and opposite ($\vec{k} \cdot \vec{B} < 0$) to $\vec{B}$, respectively. The utilized parameter varied from +1 (propagation along $\vec{B}$) to -1 (propagation against $\vec{B}$). (c) The most probable value of the angle between the wave-vector and the local magnetic field direction. The distribution of θ for (d and g) the hiss (day and night sectors respectively, $L < 5$); (e and h) the lower-band chorus ($L < 5$); and (f and i) the upper-band chorus frequency range for $L > 5$ (STAFF-SA frequency band limitation). (k–m) The equatorial distributions of θ ($|\lambda| < 5°$) for hiss, LB chorus and UB chorus respectively. The day sector distributions are indicated by red line and the night side are indicated by blue line.

the variance of the LB chorus equatorial wave normal distribution.

[4] The ray tracing explains successfully the behavior of whistler waves in the plasmasphere [*Bortnik et al.*, 2011], where the plasma is cold and non-thermal particle fluxes are rare. Outside of the plasmasphere (especially at $L > 5$), presumably Landau damping controls the wave normal distribution properties [*Bortnik et al.*, 2006]. Oblique waves have a maximal attenuation (the maximum is at $\theta \sim 50°$–$70°$ [*Ginzburg and Rukhadze*, 1975]), while quasi-parallel waves ($\theta < 30°$) propagate without significant damping. The LB chorus amplitude distribution as a function on λ presented by *Artemyev et al.* [2012] and *Horne et al.* [2005] peaked at $\lambda \sim 15°$–$20°$. At these latitudes emissions come predominately from the equatorial source at the same L-shell [*Breuillard et al.*, 2012].

[5] Therefore, wave amplifications (mainly effective for parallel waves) likely impact wave propagation up to $\lambda \sim 10°$–$15°$. Two processes - wave attenuation and amplification - must be taken into account in order to obtain the correct model of the wave distribution out of the plasmasphere.

[6] The existence of a significant population of oblique whistler waves has important implications for the description of diffusion processes due to wave-particle interactions. The results obtained for the VLF wave polarization properties (particularly the drift of the angular wave normal distribution

properties along its ray path) sufficiently impact conditions of resonance for wave particle interactions. Conventional averaging procedures could not be performed without taking into account the departure of the wave normal vectors from quasi-parallel propagation conditions and the increase of the polar angle distribution variance.

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